Brief Hydrogen Tutorial: Why Hydrogen, Why Now?

California Hydrogen Highway Network
Media Hydrogen Workshop

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Outline

- Introduction to hydrogen technologies
- Hydrogen properties
- Current hydrogen uses
- Energy context and interest
- Issues and potential for expanded hydrogen use
- Summary

Introduction to H_2 Technologies

FUEL CELL CONCEPT

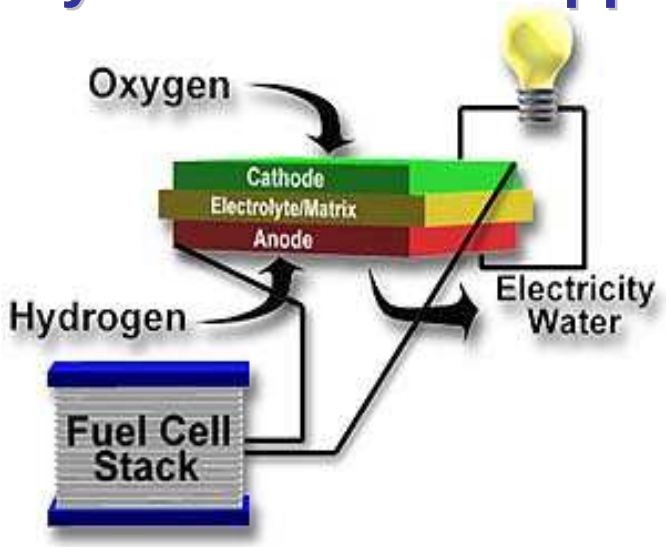
Electrode/Electrolyte Assemblies (similar to battery)

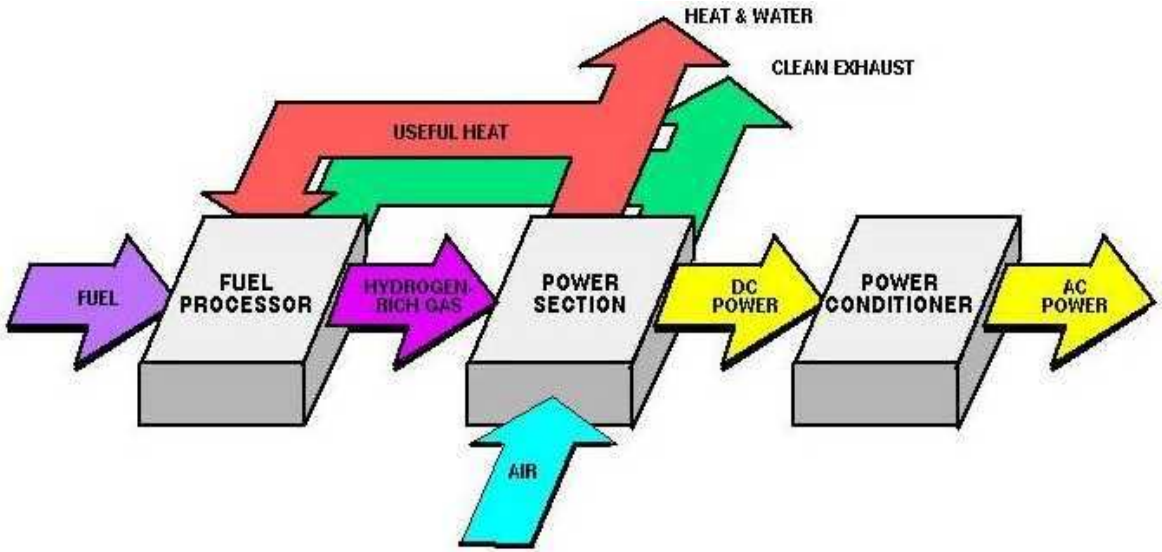
Continuous electricity production

- **Fuel and oxidant provided to separate chambers**

"Stack" - Increase Voltage/Current to Useful Levels

"System" – Make applicable to current fuels and end-use





Primary Advantages – low, to zero emissions; high efficiency

Primary Disadvantage – high cost (compared to current engines)

Introduction to H_2 Technologies

Fuel Cell Applications

STATIONARY / DISTRIBUTED POWER

- Residential/Commercial/Industrial Appl.
- Backup Power
- Remote Power
- Premium Power

TRANSPORTATION: HEAVY / LIGHT DUTY VEHICLES

- Buses / Trucks
- Passenger Vehicles
- Locomotives / Shipping

PORTABLE POWER BATTERY REPLACEMENT

Consumer Electronics	Small Motors
Laptop Computers	Boating
Cellular Phones	Lawn Mower
Camcorders, etc.	Tools, etc.

Introduction to H_2 Technologies

FC DISTRIBUTED GENERATION

Stage: Initial Commercialization

- **High-cost Local Power**
  - **e.g., 25-30 Million Homes (> $0.10 / kWhr)**
  - **@ $0.07-0.08/kWhr, $500 Annual Savings**
- **New Buildings, Homes, Business**
  - **Most have natural gas connection**

Possible Developing World Market

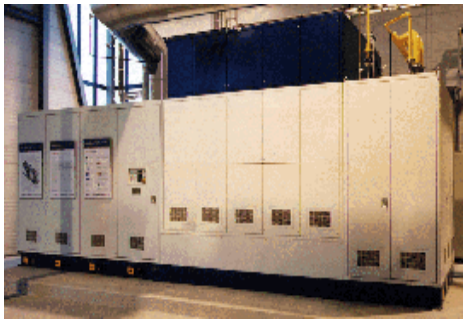
- **No Electricity - 2 Billion People**
  - **DG Paradigm may offer cost savings (cellular phone analogy)**

Plug Power

Hydrogenics

FuelCell Energy

UTC Fuel Cells



Siemens Westinghouse

Ballard-Ebara

GM / Hydrogenics

Idatech

Nuvera

Introduction to H_2 Technologies

FC TRANSPORTATION

- Buses
- Passenger Vehicles / Light Trucks
- Electric Bikes
- Golf Carts
- Trucks
- Shipping/Submarines
- Locomotives
- Snowmobiles
- Aircraft
- Other

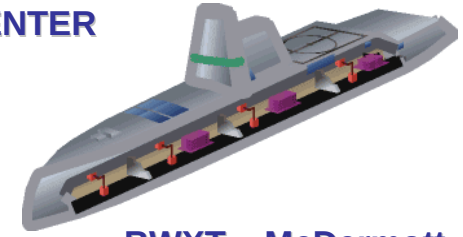
TOYOTA FCHV

NEBUS

SCHATZ ENERGY RESEARCH CENTER

BOEING

MANHATTAN SCIENTIFICS

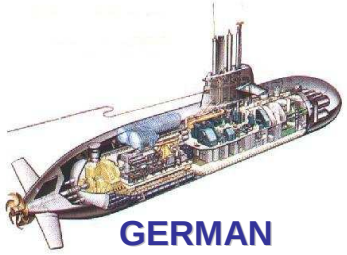


BWXT – McDermott U.S. Navy

BURLINGTON NORTHERN

FORD FOCUS

POLARIS 440 PRO X RACER



GERMAN TYPE U 212

Introduction to H_2 Technologies

FC TRANSPORTATION

Nissan

DaimlerChrysler Necar4

Toyota, RAV4
(PEMFC)

Jeep Commander

Ford P2000

Introduction to H_2 Technologies

FC TRANSPORTATION

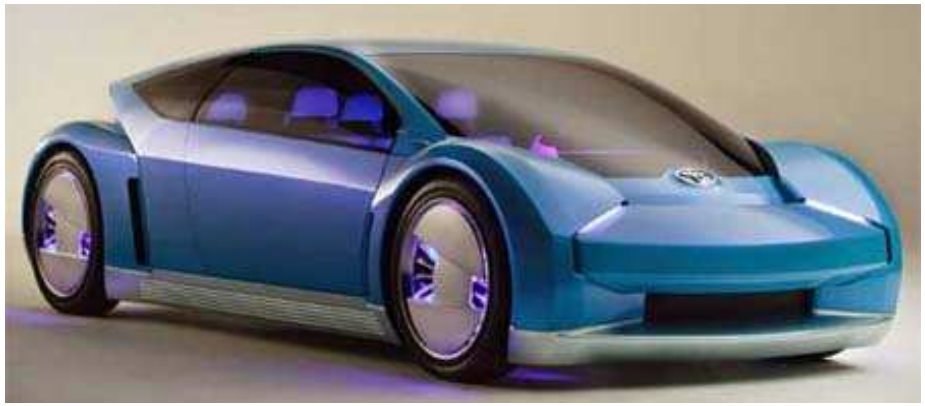
Ford Model U

Daihatsu MOVE

DaimlerChrysler – Necar5

GM-Opel FedEx FCV

Honda FCX



Toyota Fine S

Introduction to H_2 Technologies

FC TRANSPORTATION

GM Opel Hydrogen 1

Honda FCX V3

DaimlerChrysler & Ford

Mazda Demio

Nissan FCV

Toyota FCHV

Ford P2000 H2

BMW 700 Series

GM Precept

Introduction to H_2 Technologies

FC BUSES

DaimlerChrysler NeBus

UTC Fuel Cells – Georgetown Bus

Ballard - Vancouver

Mercedes-Benz Citaro 30

Introduction to H_2 Technologies

FC BUSES

Citaro FC Bus

DaimlerChrysler NeBus

Ballard – Chicago Bus Fleet

UTC Fuel Cells – Recent Georgetown Bus

Introduction to H_2 Technologies

OTHER FUEL CELL VEHICLES

Coval H2

Energy Partners

Energy Partners

Manhattan Scientifics

H Power Corp.

Outline

- Introduction to hydrogen technologies
- **Hydrogen properties**
- Current hydrogen uses
- Energy context and interest
- Issues and potential for expanded hydrogen use
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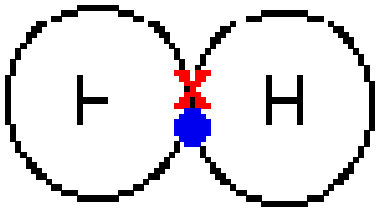
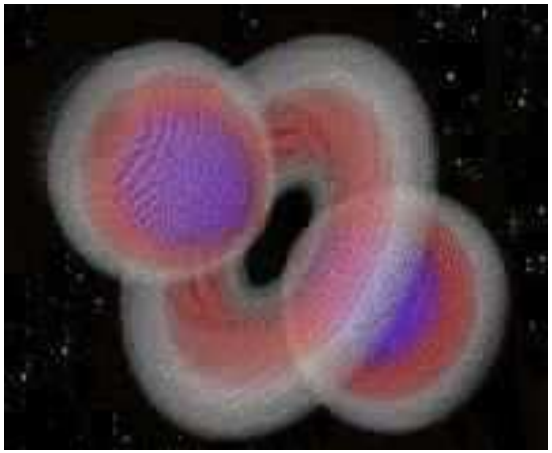
Hydrogen Properties

HYDROGEN

- The lightest element
- Usually present as an H_2 molecule: "Diatomic Molecule"
- Two protons and two electrons
  - The two atoms (protons) share the pair of valence electrons leading to a STABLE molecule:



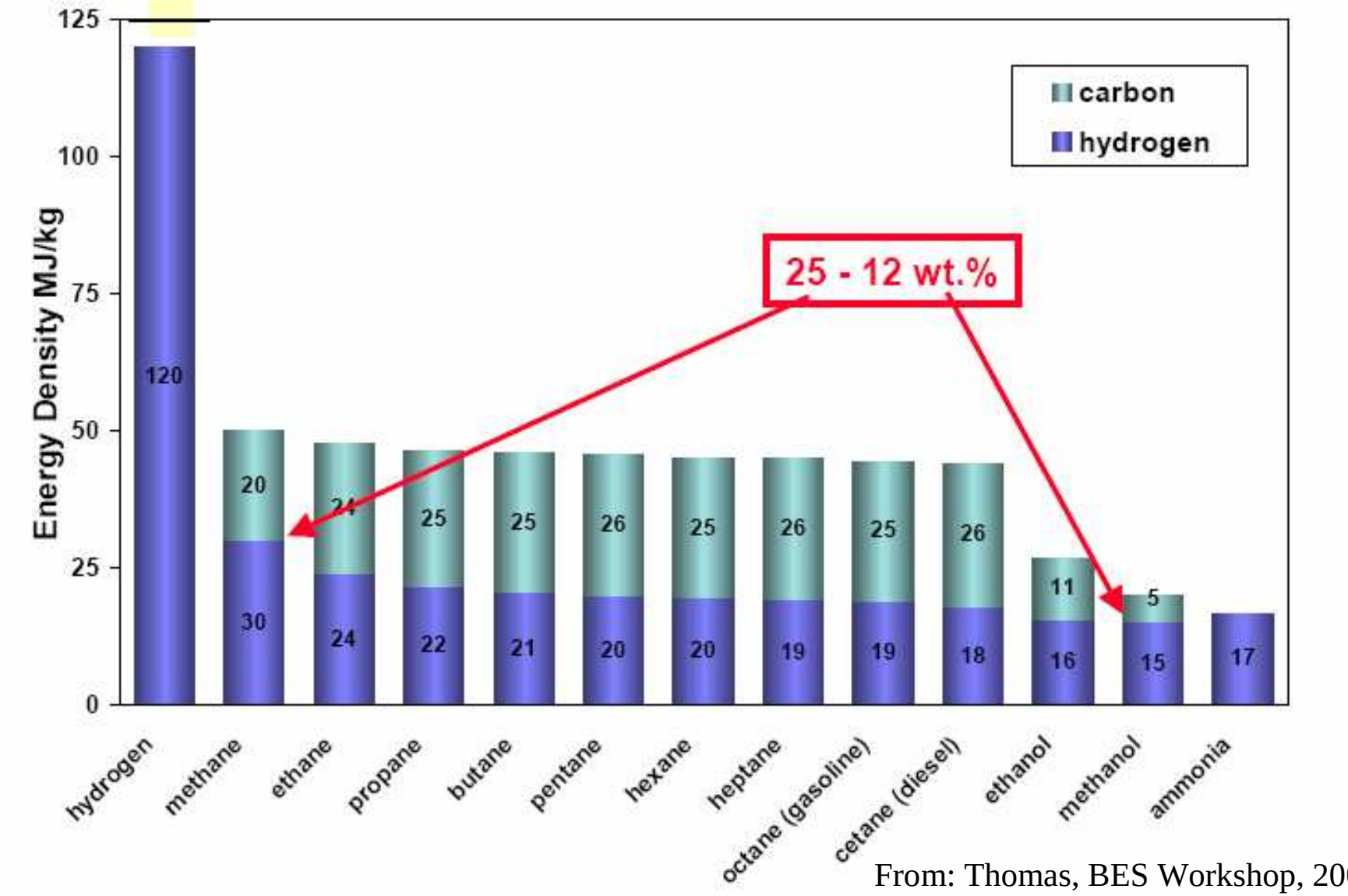


- Colorless, Odorless, Tasteless
- *Flammable*
  - Higher heating value (HHV) = 60,958 BTU/lb (141,670 kJ/kg)

Hydrogen Properties

HYDROGEN

- **Energy Content (mass basis)**

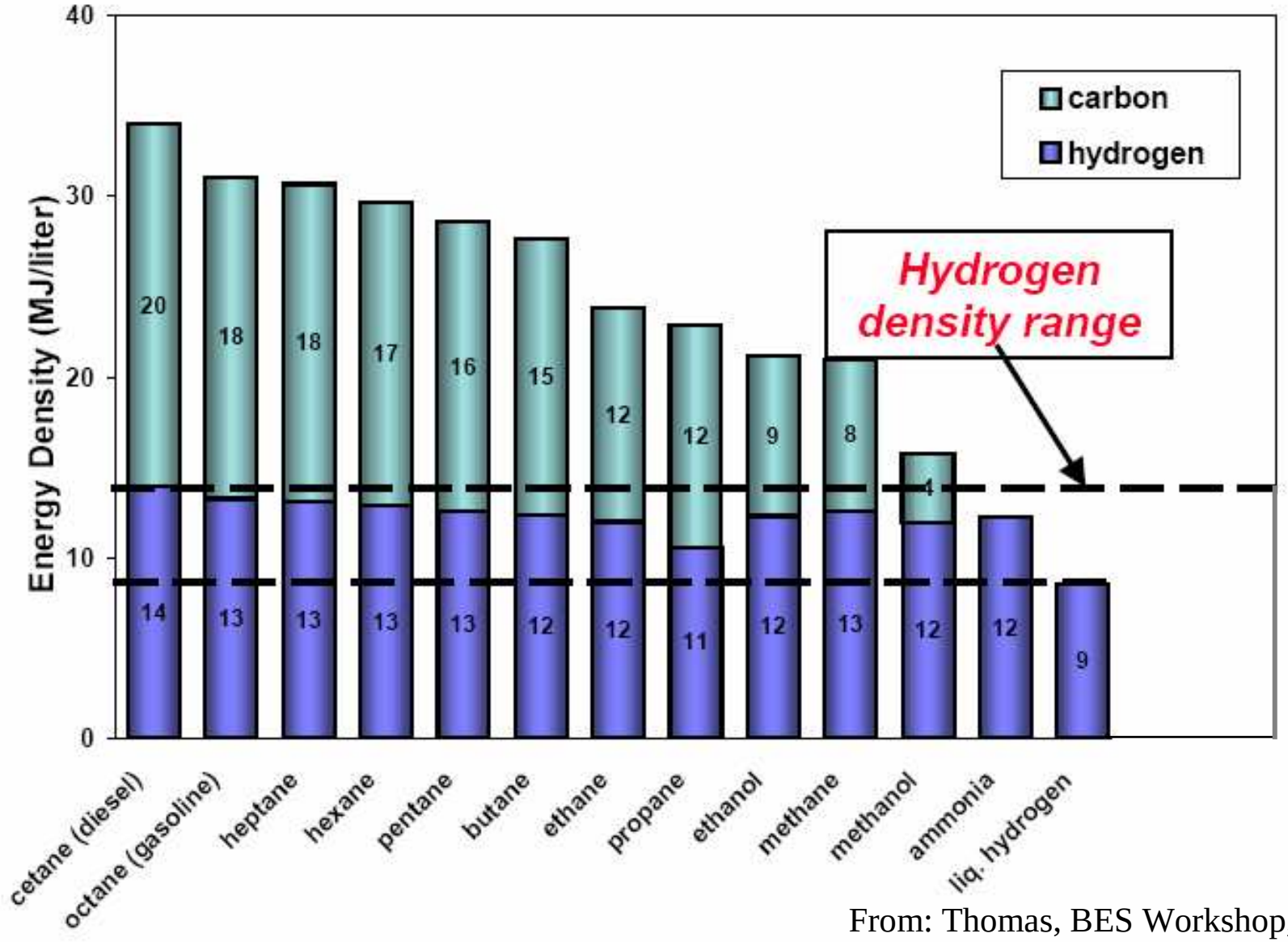


From: Thomas, BES Workshop, 2003

Hydrogen Properties

HYDROGEN

- **Energy Content (volume basis – liquid state)**

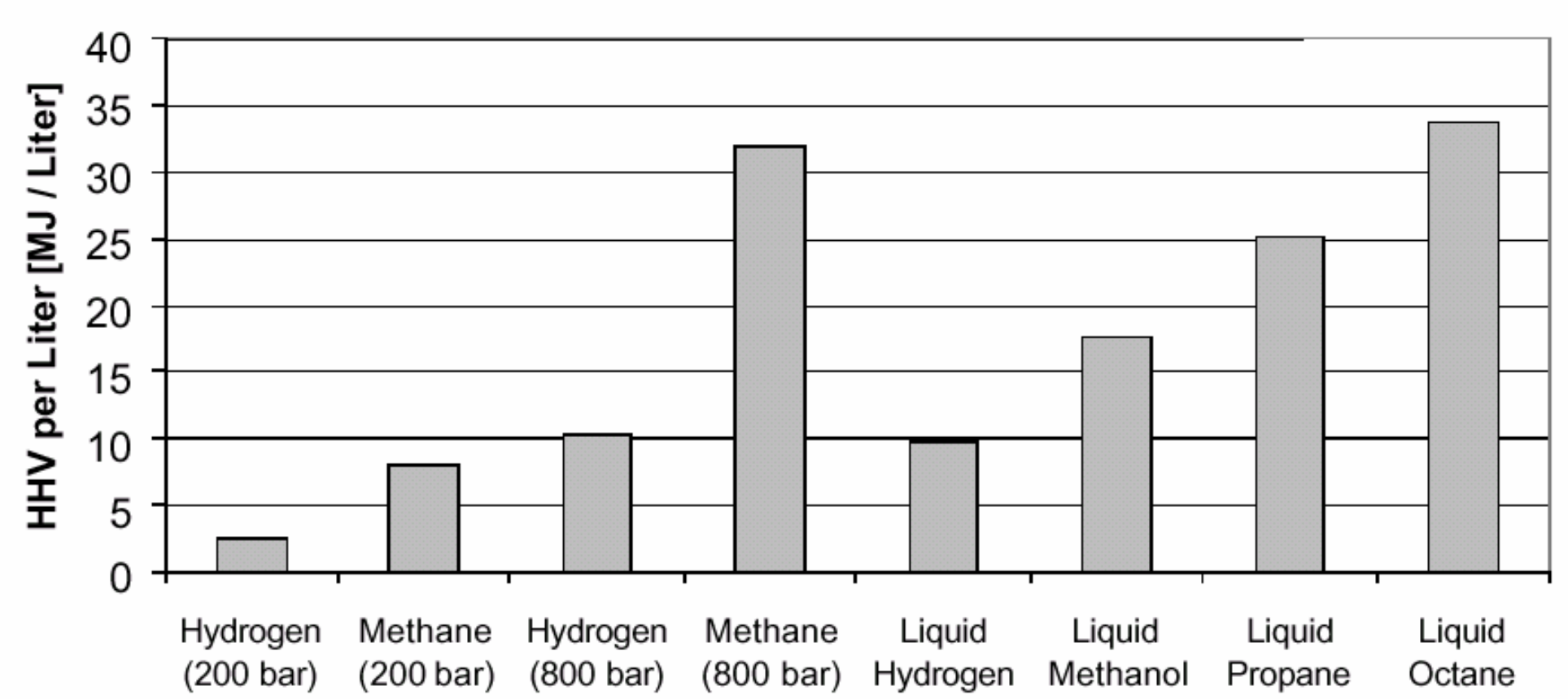


From: Thomas, BES Workshop, 2003

Hydrogen Properties

HYDROGEN

- **Energy Content (volumetric basis)**



From: Eliasson and Bossel, 2002

Hydrogen Properties

HYDROGEN

- **Flammability (or inflammability)**
  - Measured in terms of lowest and highest concentrations of the species that when premixed with air can sustain a flame in a tube or spherical container 2 inches in diameter
  - Indication of how easy it is to burn in various mixtures with air

- **Flammability Limits**

	% (by volume)	
	Lower Limit	Upper Limit
Hydrogen:	4.65	93.9
Methane:	5.00	15.0
Propane:	2.12	9.35
Decane:	0.77	5.35
Benzene:	1.40	7.10

Hydrogen Properties

Other Hydrogen Properties

- High diffusivity (e.g., 3.8 times faster than natural gas)
  - when released, H_2 dilutes quickly into a non-flammable concentration
- Low density / high buoyancy
  - H_2 rises 2 times faster than helium and 6 times faster than natural gas
- H_2 flames have low radiant heat
  - risk of secondary fires is lower
- Ignition energy (in region of interest) is similar to other fuels
- An explosion cannot occur in a H_2 tank or any contained location that contains only hydrogen
  - an oxidizer, such as oxygen, must be present (not likely to explode)
- Asphyxiation can occur with H_2, but, its buoyancy and diffusivity make it difficult to confine (low asphyxiation risk)
- H_2 is non-toxic and non-poisonous
- Very significant advances in H_2 Codes and Standards that are in place for guiding safe handling, building and installation practices (especially handling as an energy carrier / fuel)

Outline

- Introduction to hydrogen technologies
- Hydrogen properties
- **Current hydrogen uses**
- Energy context and interest
- Issues and potential for expanded hydrogen use
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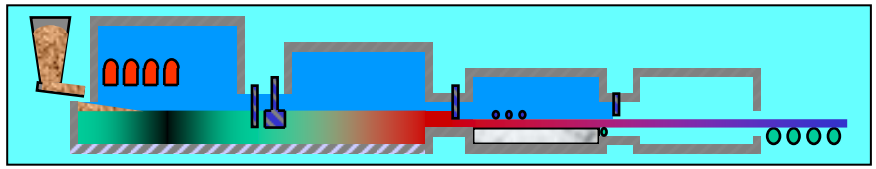
Current Hydrogen Use

Current Hydrogen Use

- **Hydrogen is widely used today (> 90 billion ft^3/year)!**
- **Used mostly as a chemical, rather than a fuel, in a variety of commercial applications**
  - ***Petroleum refining processes***
  - ***Chemical process raw material*** **(e.g., plastics, food-grade oil, ammonia)**
  - **Used as a reducing gas in *metals processing* (e.g., steel)**
  - ***Electronics industry*** **(e.g., silicon wafers and computer chips)**
  - ***Rocket engine fuel*** **(e.g., Space Shuttle)**



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Energy Context and Interest

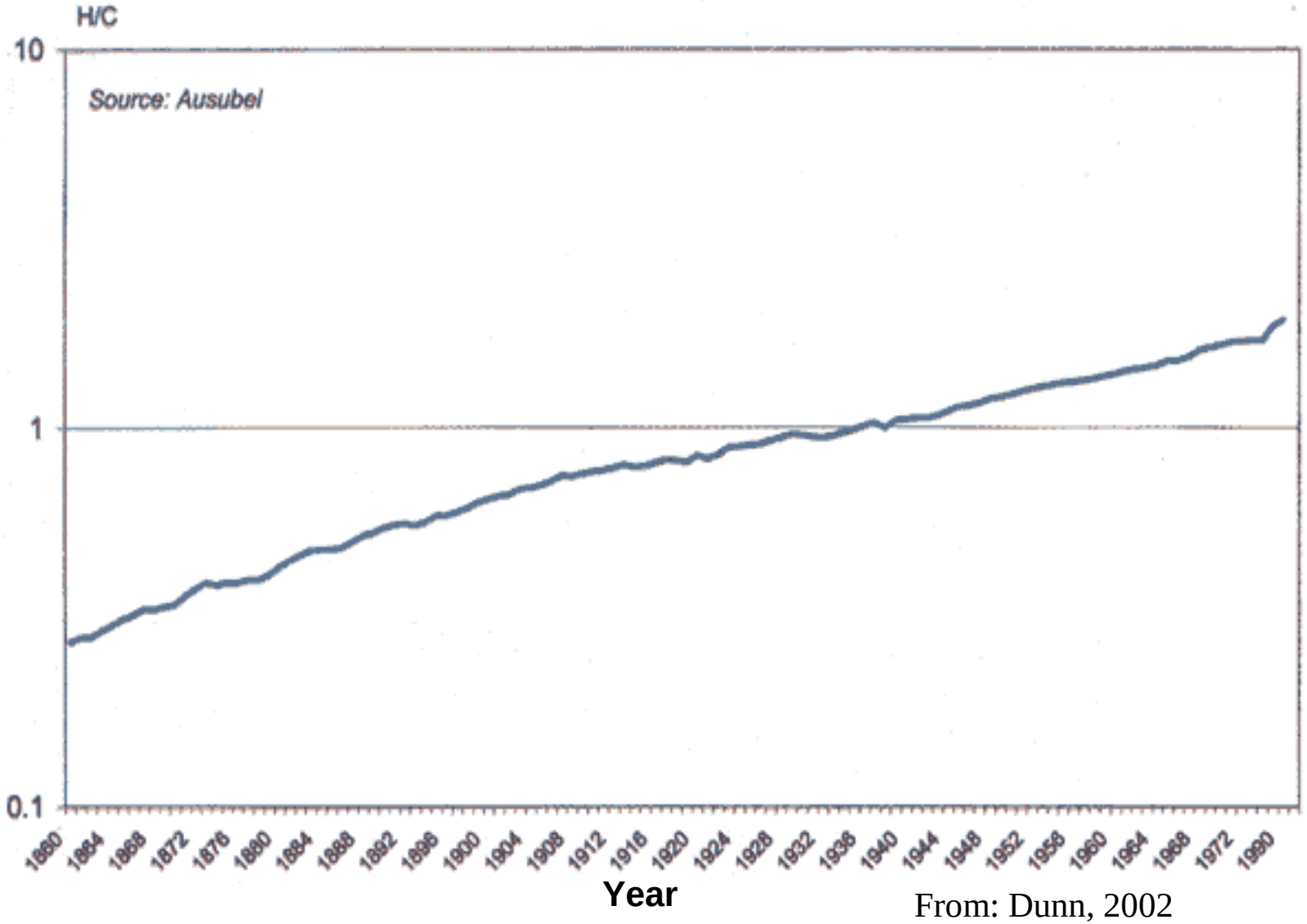
History

- Jules Verne 1874 novel “The Mysterious Island”
  - Idea of an energy system based on water - and hydrogen
- Phrase 'hydrogen economy' coined in 1970 by GM engineers
- Four decades of relative neglect
- Recent interest and upheaval due to several factors
  - Security
  - Environment
  - Technology advances
  - Policy, etc.
- Is the energy world returning to chaos of early 20th century?
  - New transportation fuels and technologies
- Hydrogen related innovations are now important elements of energy industry strategy
  - Annual turnover of $2 trillion

Energy Context and Interest

Fuel Hydrogen Content

- Increasing hydrogen content in fuels (1860 – 2000)

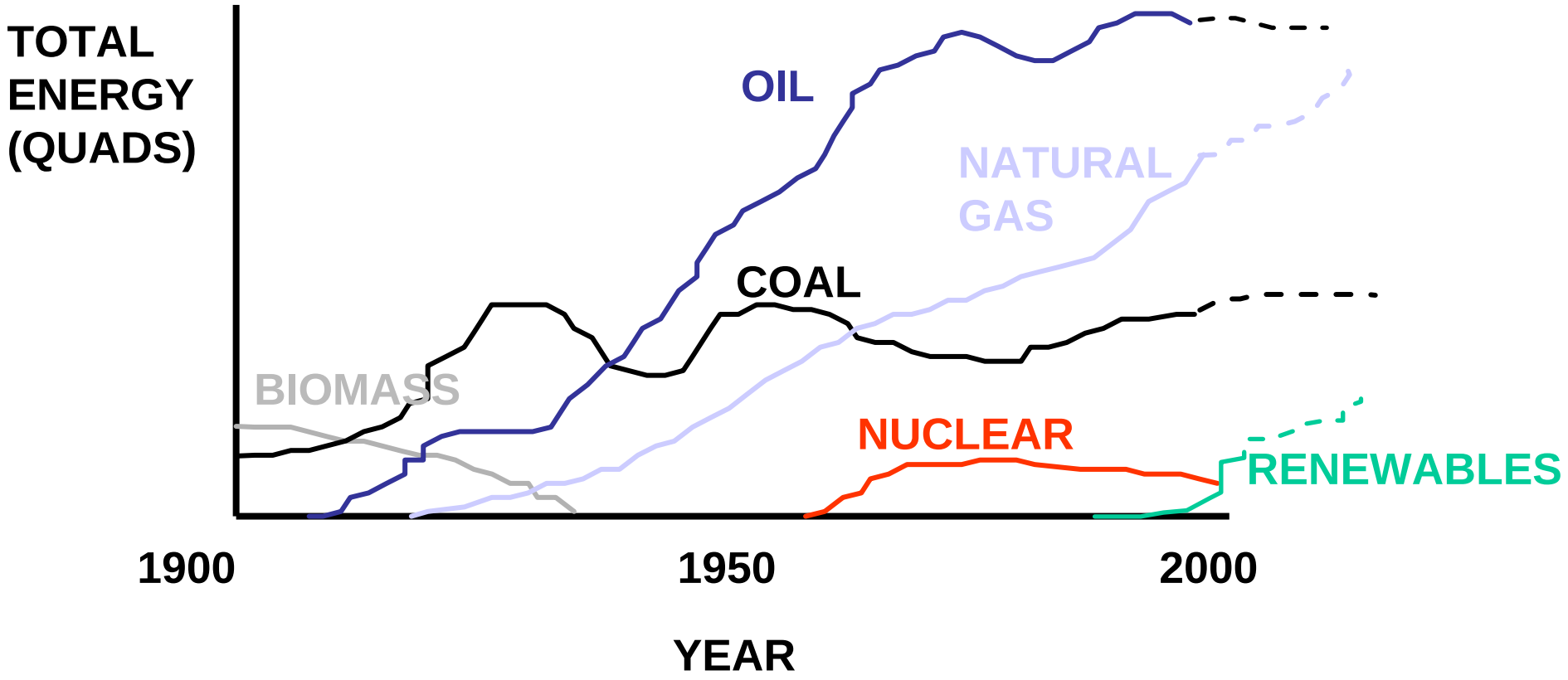


From: Dunn, 2002

Energy Context and Interest

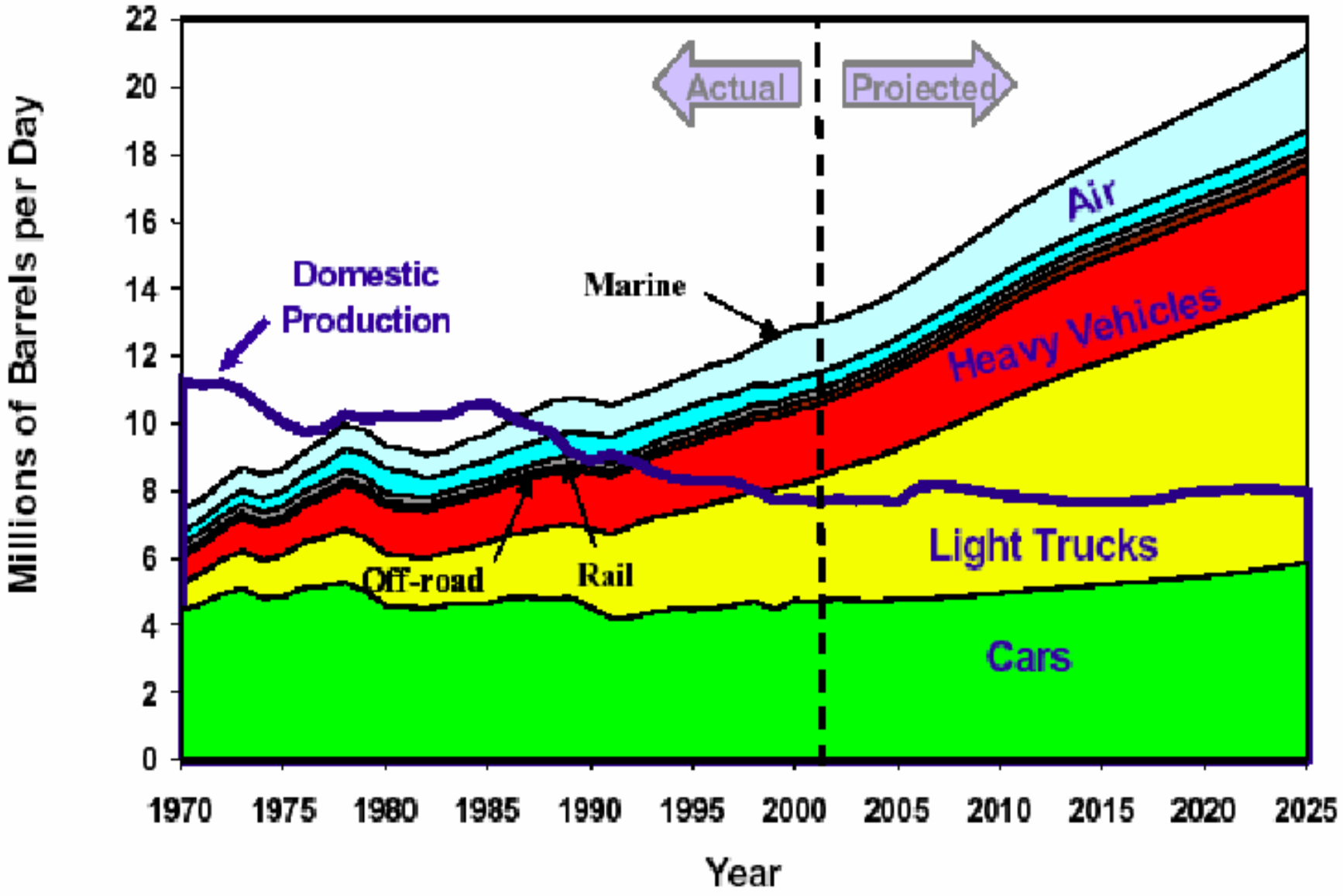
Energy Use

- **Worldwide Historical Fuel Use to Meet Energy Demands**



Energy Context and Interest

Domestic oil production and vehicle consumption



Source: EIA, U.S. DOE

Energy Context and Interest

Why use Hydrogen?

ENVIRONMENT:

- Conversion to thermal or electrical energy produces only water as a by-product ($H_2 + ½ O_2 \rightarrow H_2O$)
- Compared to HC combustion: NO_x, SO_x, CO, HC, CO_2, lower
- Conversion devices may be more energy efficient (use less fuel, less emissions per unit of useful work): e.g., fuel cell

ENERGY SECURITY, INDEPENDENCE:

- Hydrogen can be made from domestic sources of primary energy (energy security, independence):
  - Natural gas
  - Electricity (renewable or grid)
  - Oil
  - Coal

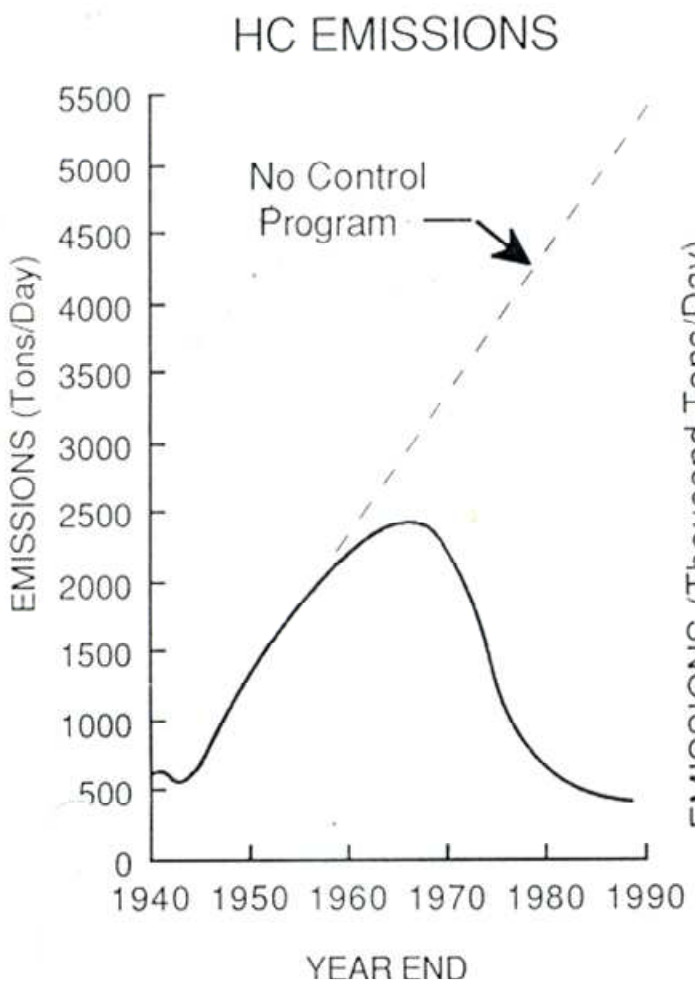
ECONOMICS:

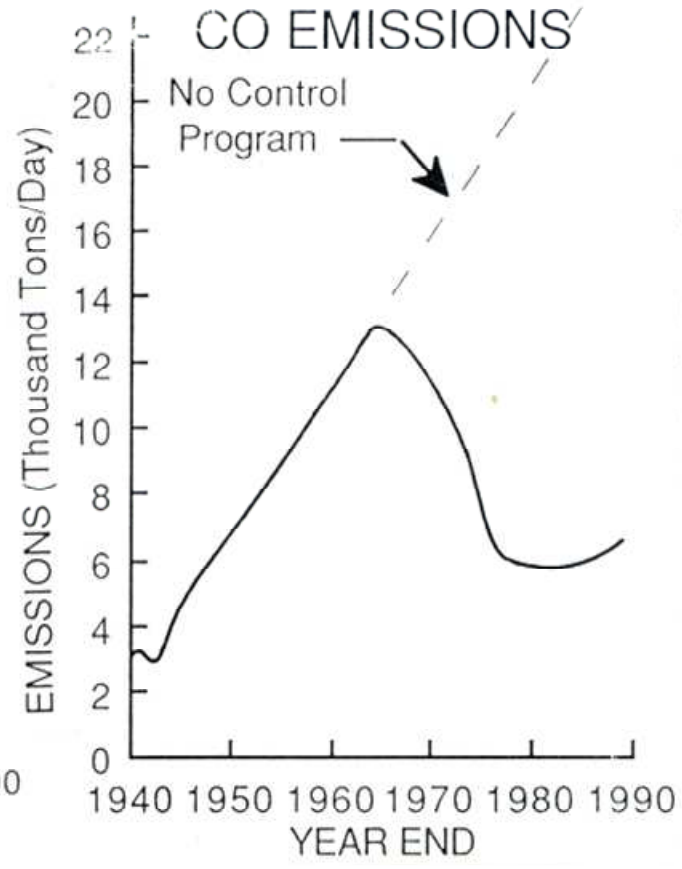
- Cheap sources of fuel may be running out (~20-50 years)
  - Oil
  - Natural gas

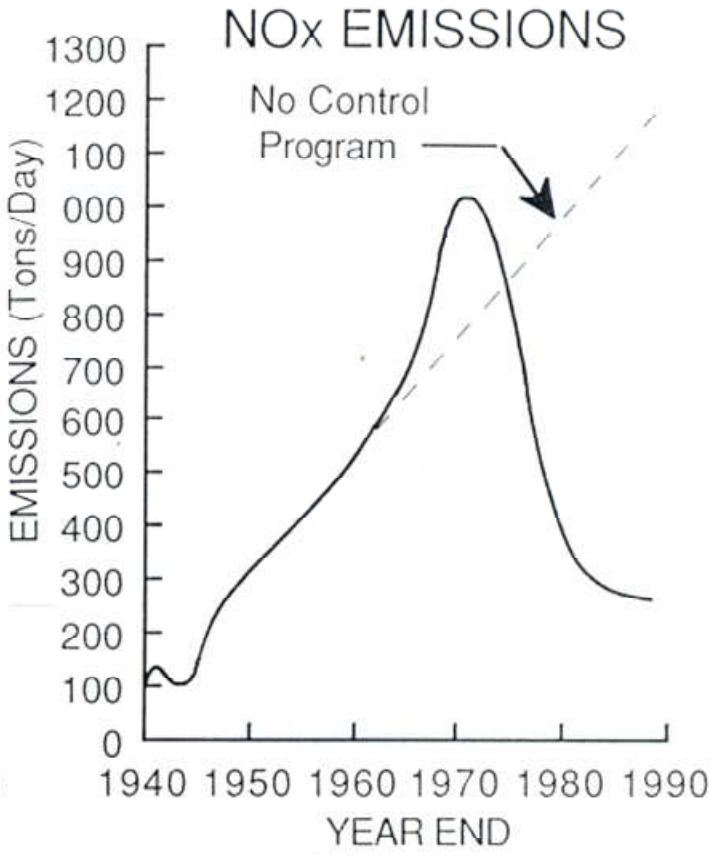
Energy Context and Interest

Why use Hydrogen?

- **Limits to Environmental Sensitivity of Current Technologies (e.g., Automobile Engine)**

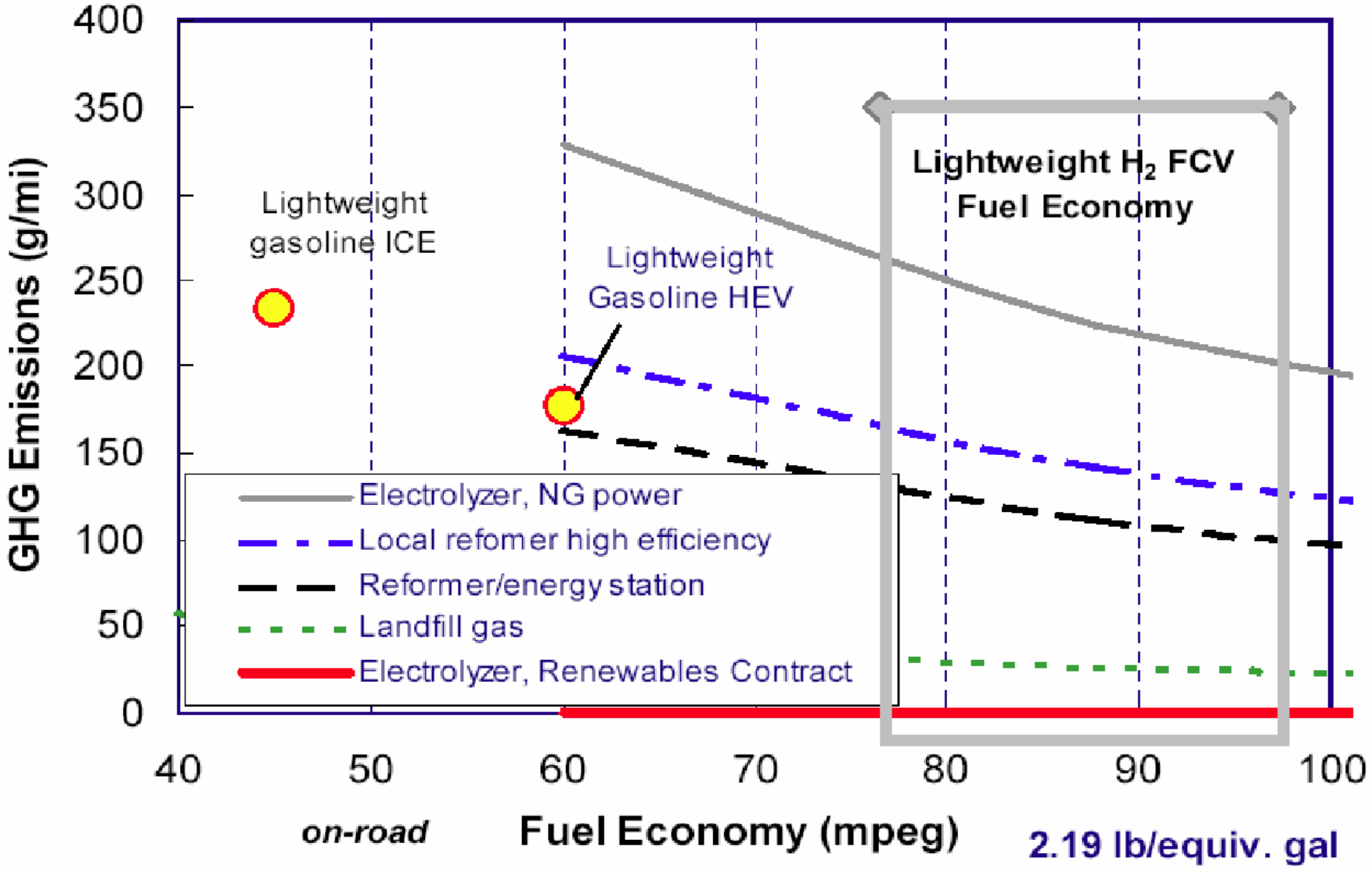






Energy Context and Interest

GHGs for Hydrogen FCVs vs. ICE Vehicles



Source: Bevilacqua-Knight, 2001

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Issues for Increased H_2 Use - Safety

HYDROGEN SAFETY

Fire

Excessive Tank Pressure
(Blocking all safety valves)

Mechanical Damage

Extensive testing & safety standards applied to all hydrogen apparatus

Hydrogen Leak Gasoline Leak

Courtesy: BMW Group, 2000; Garrity, Murdoch Univ., 2002

Issues for Increased H_2 Use - Safety

HYDROGEN SAFETY

H_2 characteristics

- Broadest flammability limits
- Highest diffusivity
- Lowest density

Need to handle carefully, but, can be safer than gasoline!

- In the event of an accident – creation of a flammable mixture is less likely with hydrogen than with gasoline

H_2 is challenging to handle and requires consistent application of best practices

But – there is no significant technological hurdle

Rather there is a need for education at several levels

- Engineers, designers, builders (codes and standards)
- End-Users
- General Public

Issues for Increased H_2 Use - Storage

High pressure hydrogen tank

Issue: Volume

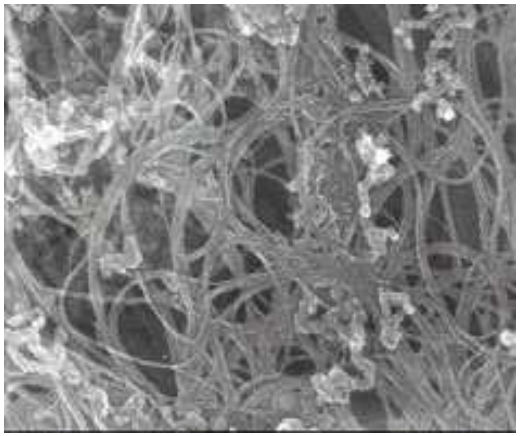
Hydrogen-absorbing alloys/hydrides tank

Weight

Liquid hydrogen tank

Boil-off gas

Carbon nanotubes



Issue: Actual storage capability?

Chemical hydrides

$NaBH_4$

$Decalin(C_{10}H_{18})$ $Naphthalene(C_{10}H_8)$

$- H_2$

Catalyst

$+ H_2$

Handling / Recycling

Courtesy: Kawai,Toyota, 2002

Issues for Increased H_2 Use – Life Cycle

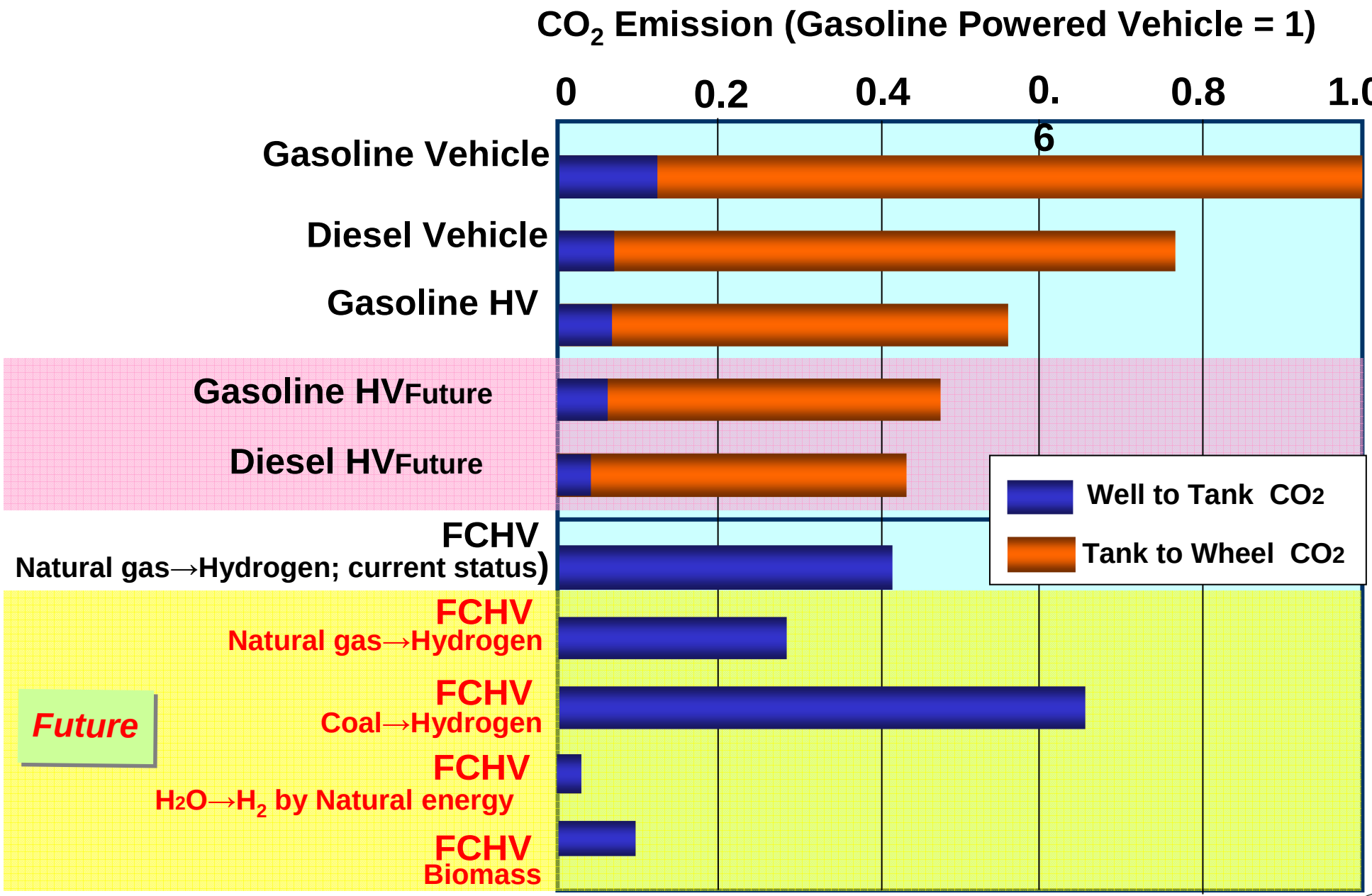
"Well- to- Wheel" Fuel Cycle Emissions

EXAMPLE:

- Extraction of Original Resource (e.g., in Saudi Arabia)
- Processing of Bulk Fuel (e.g., in Saudi Arabia)
- Storage of Bulk Fuel (e.g., in Saudi Arabia)
- Transportation of Bulk Fuel (e.g., in oil tanker)
- Bulk Storage (e.g., in California refinery)
- Production of Refined Product (e.g., in California refinery)
- Transportation and Distribution (e.g., to filling stations)
- Refined Product Storage (e.g., in filling station)
- Vehicle Storage (e.g., evaporative emissions)
- Vehicle Use (e.g., combustion emissions)

VERY IMPORTANT TO INCLUDE "WELL-TO-WHEEL" OR "LIFE-CYCLE" IMPACTS IN ANALYSES OF ALTERNATIVE FUELS

Issues for Increased H_2 Use – Life Cycle

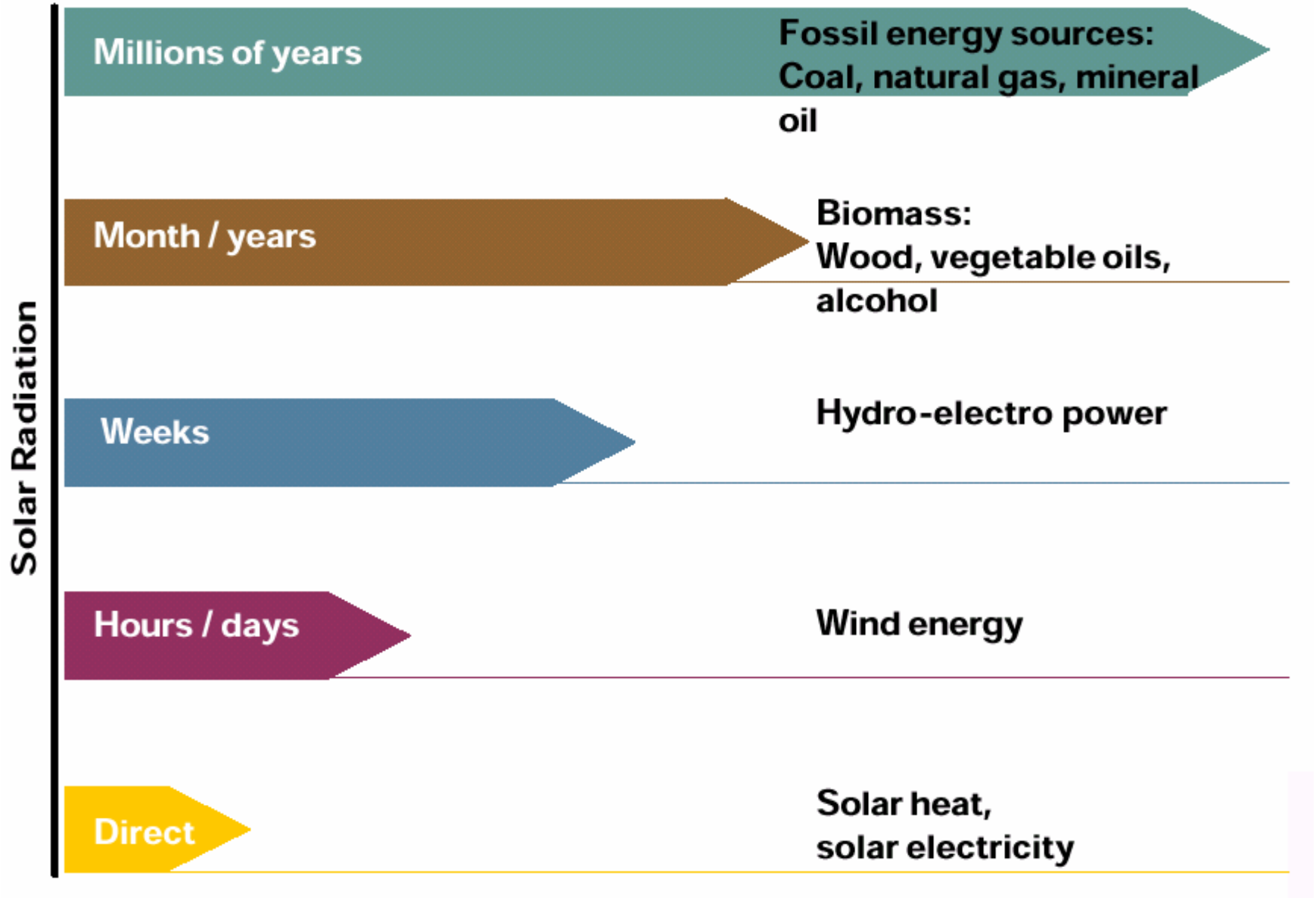


Toyota's Calculation □10-15 mode, Hydrogen fueled FCHV

Courtesy: Reinert, Toyota, May, 2003

Issues for Increased H_2 Use – Life Cycle

Primary Energy: All We Use Comes from the Sun



Courtesy: BMW Group, 2000

Issues for Increased H_2 Use – Life Cycle

Societal "choices" that impact Life Cycle

- Primary energy used for hydrogen production
- Hydrogen transportation technology
  - Pipeline, wires, …
  - Ships, trains, trucks, …
- Location of hydrogen infrastructure
- Storage technology
  - Pressurized
  - Liquid
  - other
- End-use technology
  - Fuel Cells
  - Internal combustion engine

- Sustainability requires that we use resources (produce products) at the same *rate* at which they are naturally replenished (consumed)

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Summary – Why Hydrogen, Why Now?

- **Hydrogen is one of only a few options (others: biofuels, battery EVs/plug-in HEVs) that can simultaneously address**
  - **Air pollution**
  - **Greenhouse gas (GHG) emissions**
  - **Energy and national security concerns**
  - **Energy sustainability (economic and environmental)**
    - **climate change**
    - **"peak oil" production**
    - **high prices**
    - **geopolitical concerns**
- **Great technological progress has been made (last 15 years)**
  - **Hydrogen technology**
  - **Fuel cell technology**
  - **Electric drive trains and Hybrid vehicles**
- **Challenges remain**
  - **Life Cycle, Cost (FCV, H_2 infrastructure), H_2 Storage**

Thank You for Your Attention!